



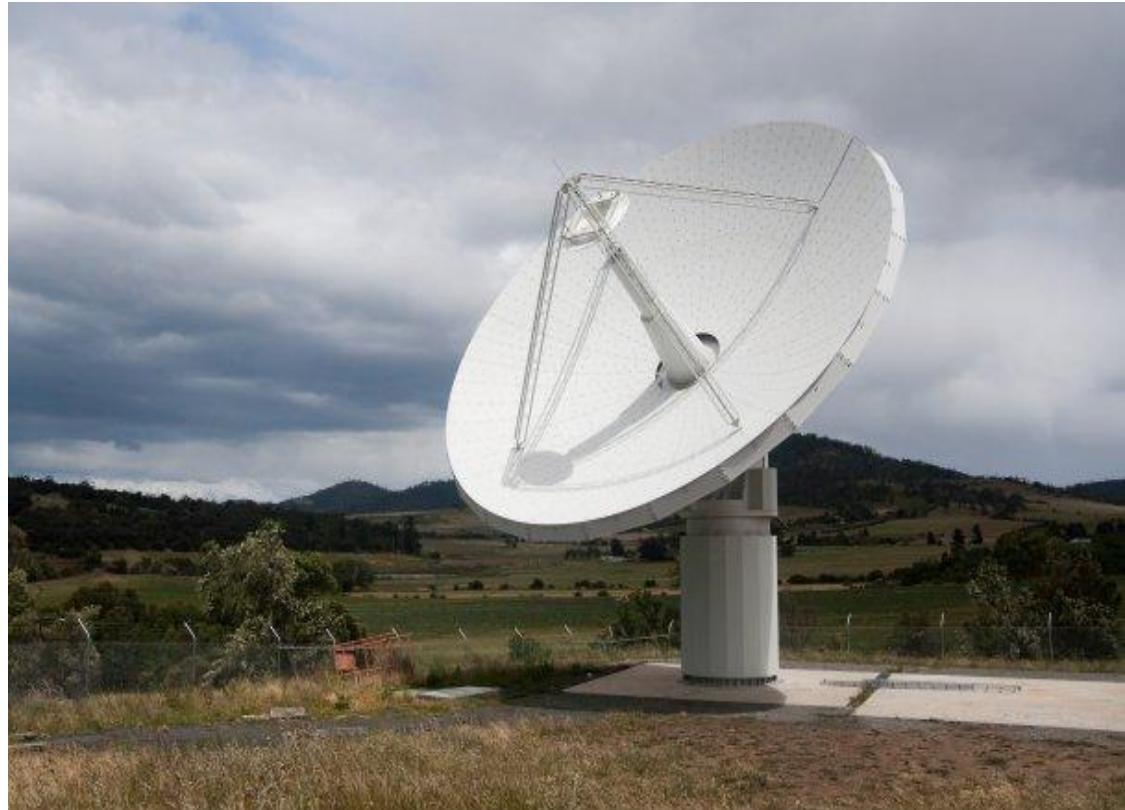
Assessing the Accuracy of Geodetic Measurements for the VLBI2010 Observing Network

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What is the level of systematic error for VLBI2010?

Errors considered here:

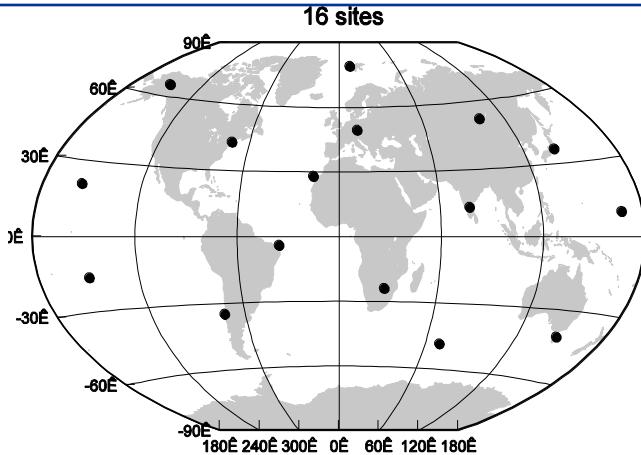
- Troposphere turbulence
- Clock error
- Observation noise
- Hydrostatic troposphere mapping function
- Antenna gravitational deformation
- Site pressure error



=> Error Budget



VLBI2010 16-Station Simulation Network



- Only considered case of 60 obs/hour
- 16-site network
- Corresponds to ~ 5 deg/s azimuth slew rate (~ Patriot antenna slew rate)
- Uniform sky schedule (Searle/Petrachenko)

	Lat	Lon		Lat	Lon	
KERG	-49	70		KOKEE	22	-160
HOBART26	-42	147		MAS1	27	-16
TIGOCONC	-36	-73		TSUKUB32	36	140
HARTRAO	-25	27		WESTFORD	42	-71
TAHITI	-17	-149		WETTZELL	49	13
FORTLEZA	-5	-35		BADARY	51	102
KWJ1	9	167		GILCREEK	64	-147
BAN2	13	78		NYALES20	78	12



Observation Error Model



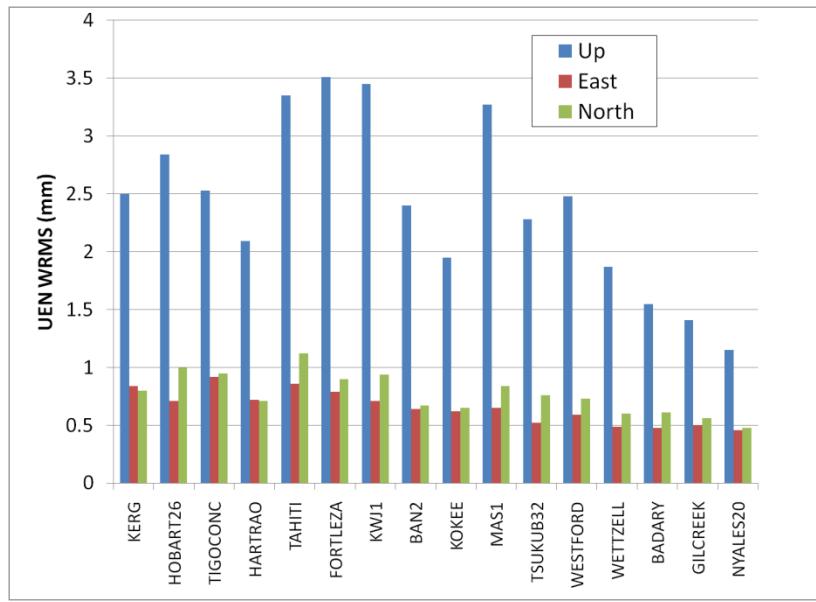
$$O - C = [m_{wet}(el_2)\tau_{wz2} + clk_2 + \tau_{s2}] - [m_{wet}(el_1)\tau_{wz1} + clk_1 + \tau_{s1}] + \sigma_{obs}$$

turbulence clocks Systematic errors:
- gravitational deformations
- hydrostatic mapping function
- pressure observation

- Clock delays for each station modeled as random walk +integrated random walk processes corresponding to clock Allan variance
- Wet delay contribution based on Kolmogorov turbulence delay model
- Add a white noise contribution corresponding to the observation uncertainty



Troposphere Turbulence



Increasing Latitude →

Latitude/seasonal/site-height dependent turbulence model:

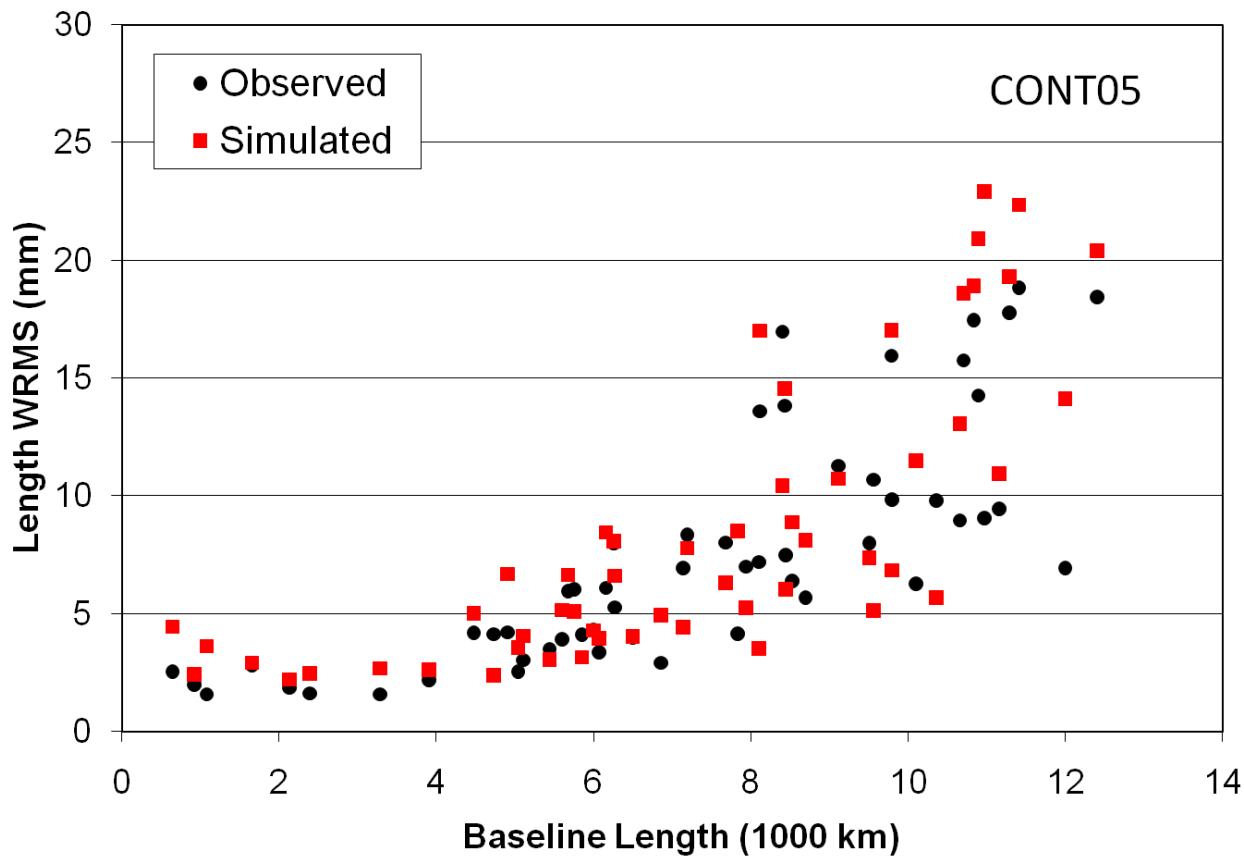
- Based on Treuhaft-Lanyi Kolomogorov turbulence model
- Used refractive index structure constant C_n and heights H computed by Tobias Nilsson from global distribution of high resolution radiosonde site data
- C_n increases towards equator corresponding to increased water vapor
- Comparison of simulations with CONT05 data => overestimate by ~20%



CONT05 Test



Comparisons with Observed Data



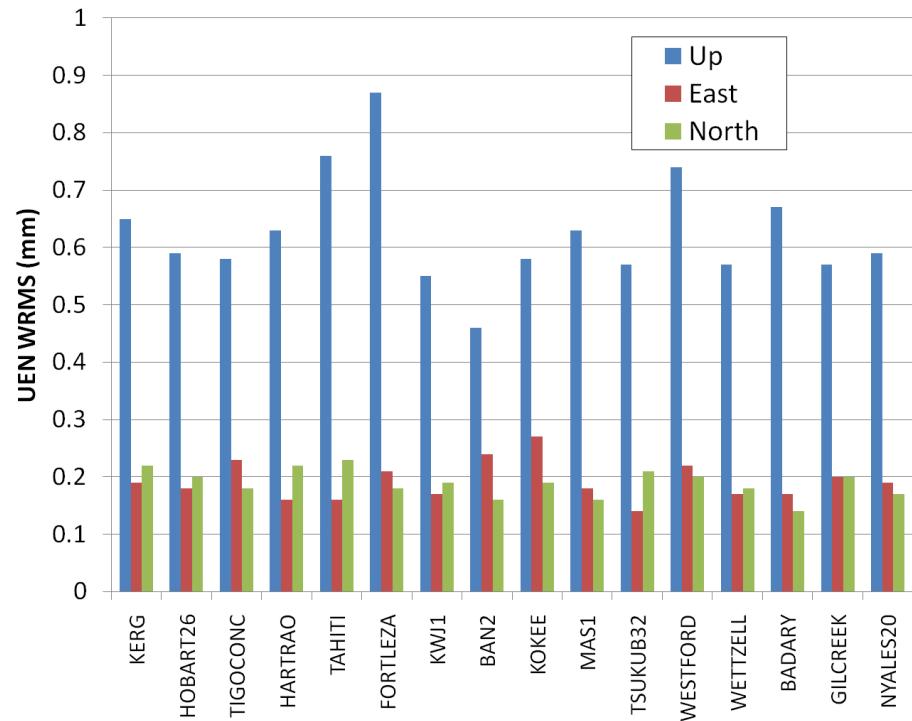
Length scatter
Simulate/observed
 1.2 ± 0.4



Clock Error



Effect of clock error of 1×10^{-14} @ 50 min



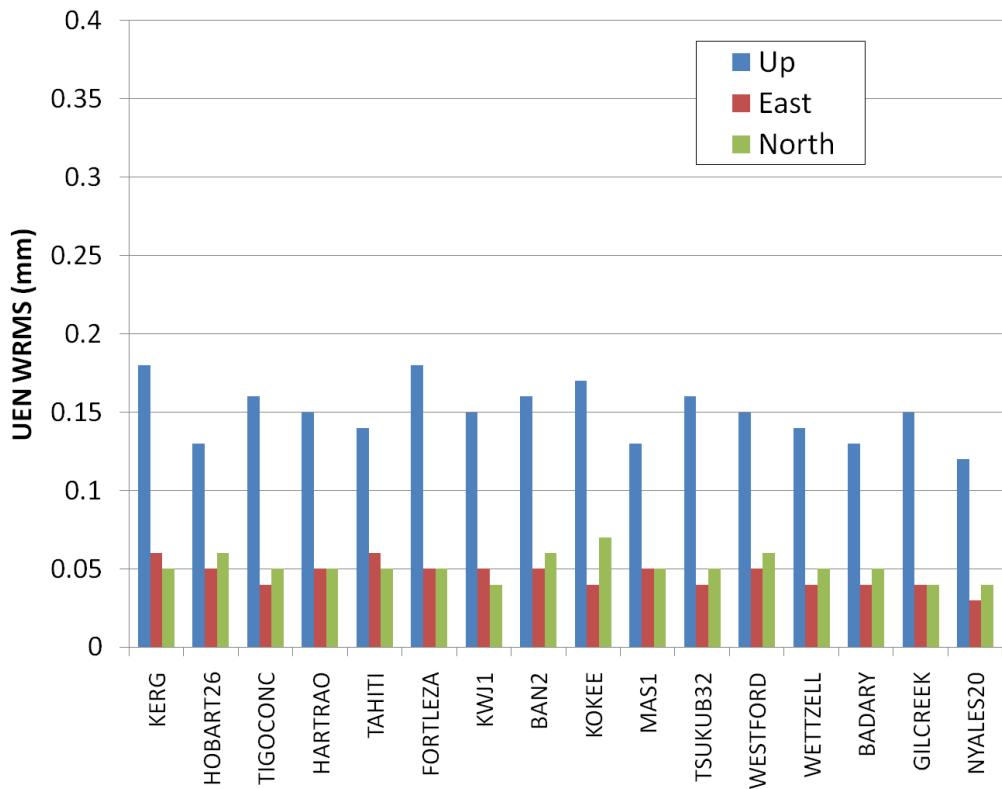
Vertical precision $\sim 0.5 - 0.8$ mm
Vertical bias < 0.2 mm



Observation Noise Error

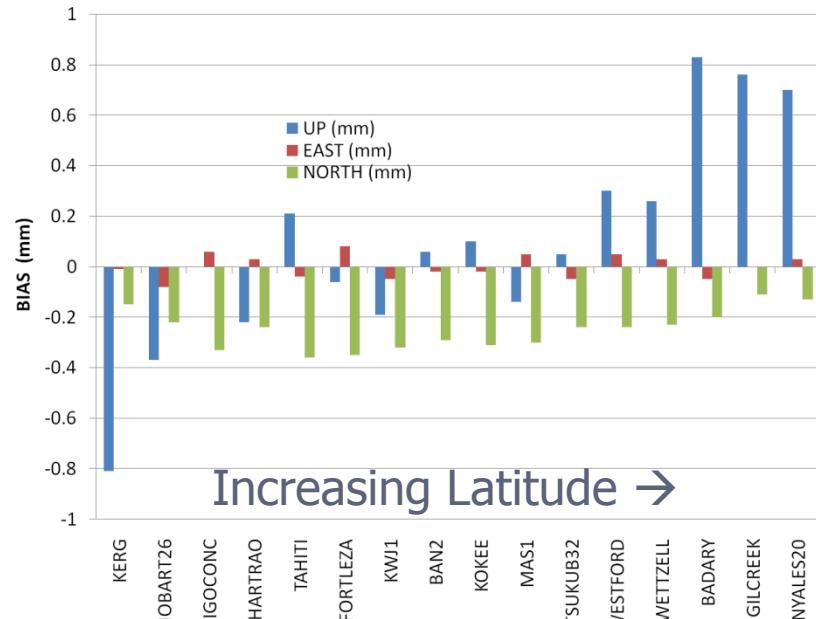
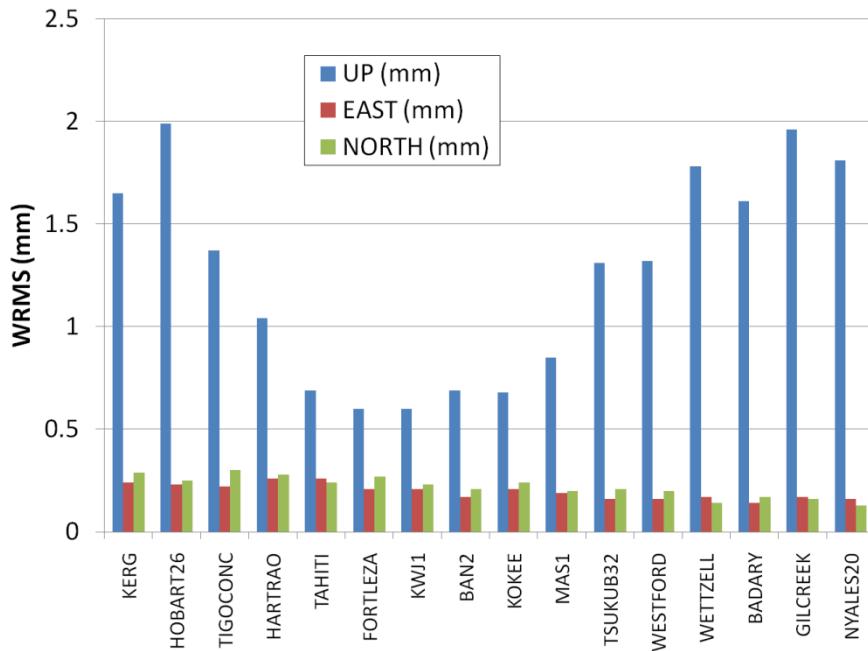


Effect of 4 psec nominal VLBI2010 observation noise



Vertical precision ~ 0.15 mm
Vertical bias < 0.05 mm

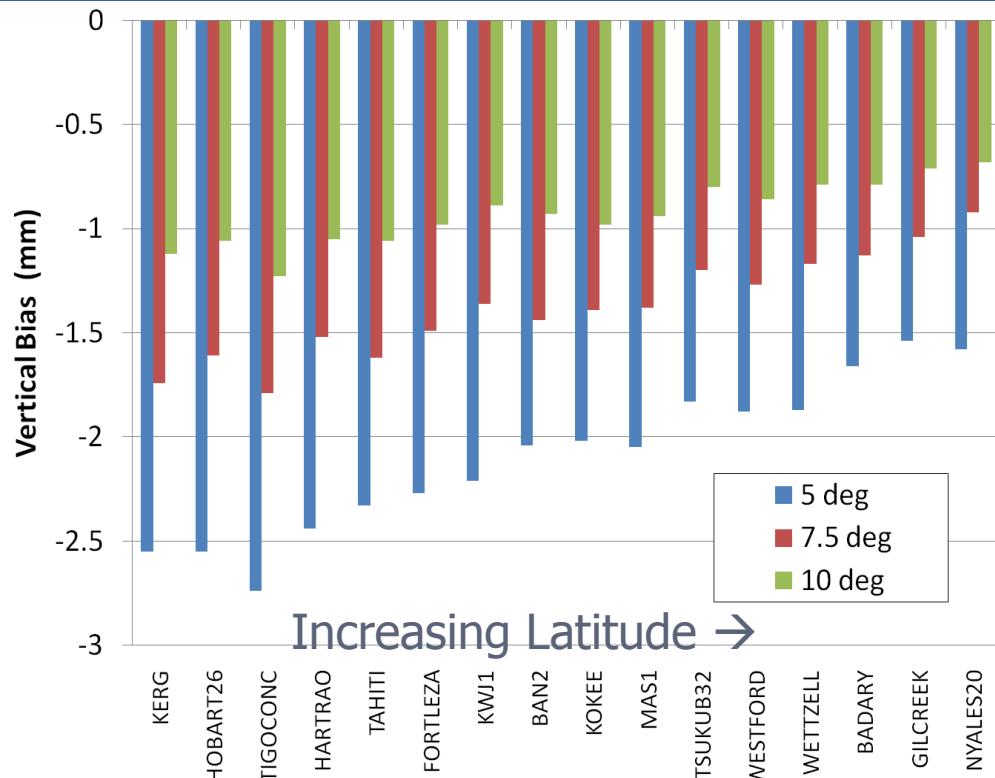
12 psec noise =>
 ~ 0.5 mm precision
 < 0.05 mm bias



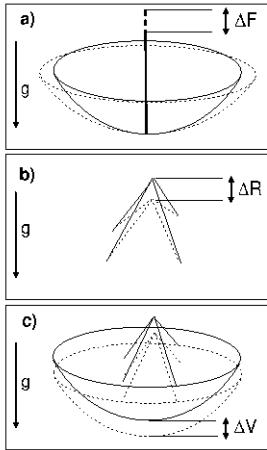
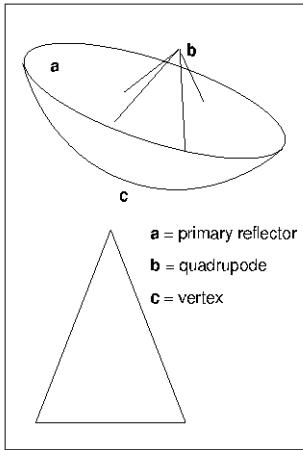
Latitude dependent mapping function errors

- Based on comparisons with 1-D raytracing radiosonde profile data (assume troposphere is symmetric in azimuth)
- WRMS delay error at 5° elevation from Niell [2006]
- Bias error at 5° of VMF1 from Bohm et al. [2006]
- Simulated as error in the continued fraction a-coefficient of the mapping function

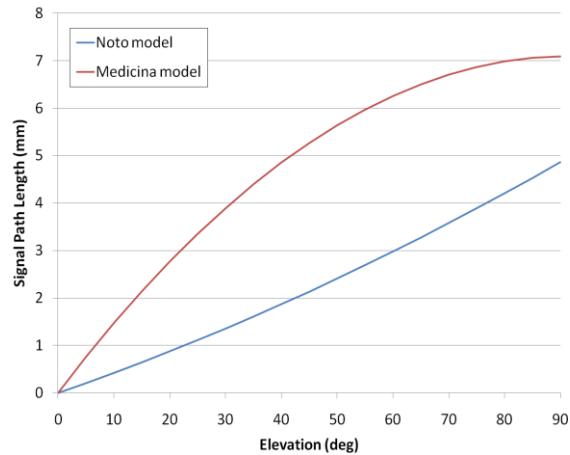
Site Pressure Error



- Vertical bias arising from a 10 mbar surface pressure error => 0.2 mm/mbar
- Caused by difference in the hydrostatic and wet mapping functions (scale heights are different 10-12 km vs. 2-3 km)
- Error decreases by a factor of ~2 between 5 and 10 elev cutoffs
- Avoid problem completely by: a) pressure sensor calibration, b) no missing data c) account for sensor height relative to reference point



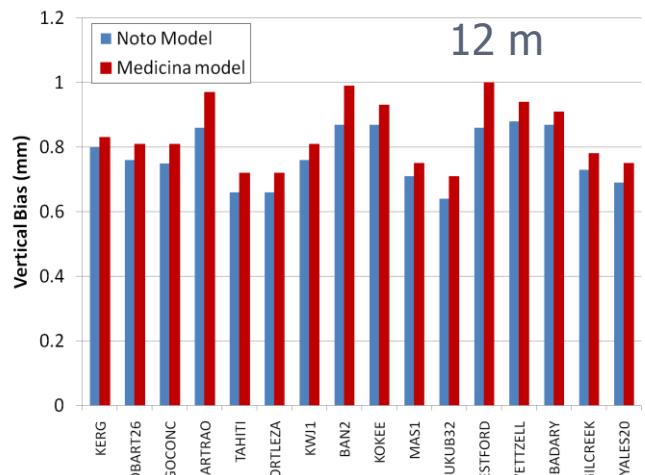
Signal path effect for 32m



$$\Delta L(e) = \alpha_F \Delta F(e) + \alpha_V \Delta V(e) + 2\alpha_R \Delta R(e)$$

- Model of deformation from Clark and Thomsen
- Measurements of Noto and Medicina (Sarti and Abondanza)
laser scanner + terrestrial survey + finite element model
- Scaled the models down from 32 m to the 12 m VLBI 2010 antenna size
 - The effect on vertical estimates from 2 models is nearly the same
- Effect is a vertical bias of 0.7-1 mm for the 12 m

Effect on vertical estimates





Site Vertical Position Error Budget



Error Source	Bias (mm)	RMS (mm)
Troposphere turbulence ¹	< 0.5	1-3
Hydrostatic mapping function ¹	0.5-1.5	0.5-2
Asymmetric atmosphere delay ²	?	?
Clock error (1×10^{-14} @ 50 min)	< 0.2	0.6
Gravitational deformation	0.6-1.0	-
Thermal deformation	0.07 (mm/°C)	-
Pressure error ³	0.15-0.25 (mm/mb)	-
Observation noise (4 ps sigma)	< 0.1	< 0.15
Source structure	?	?
????		

1. Site latitude dependent
2. 3D raytracing of gridded global weather model data should improve this
3. ParoScientific Met3A precision: 0.1C , 0.08 mb and 0.01 mb/yr



Conclusions and Future Work



- Biases at the 1-2 mm level in site position estimates from several sources
 - (1) troposphere mapping function error
 - (2) gravitational antenna deformations
 - (3) site pressure errors
- Gravitational deformation of VLBI2010 antennas needs to be directly measured
- Errors due to troposphere turbulence have latitude dependence but do not result in significant biases
- Further work will be done to determine possible systematic effects on EOP estimates and wet troposphere parameter estimates
- Other effects need to be investigated: e.g., Source structure
- We will also investigate the dependence of estimated parameter biases on the rate that stations observe and the observation integration time



Observation Error Model



- Clock delays for each station modeled as random walk +integrated random walk processes corresponding to clock Allan variance
- Wet delay contribution based on Kolmogorov turbulence delay model
 - Described in Treuhhaft and Lanyi (1987)
 - Used procedure of T. Nilsson (2007) to generate turbulent delays
 - Model parameters are effective troposphere height, wind velocity, and refractive index structure constant C_n
- Add a white noise contribution corresponding to the observation uncertainty
- Add contributions from systematic errors

$$O - C = [m_{wet}(el_2)\tau_{wz2} + clk_2 + \tau_{s2}] - [m_{wet}(el_1)\tau_{wz1} + clk_1 + \tau_{s1}] + \sigma_{obs}$$



Simulation Procedure



- Specify network antenna locations, antenna sensitivities, slew rates, SNR requirements
- Run a simulation observation file from an observing schedule for a given network with the VLBI SOLVE analysis program
- Perform Monte Carlo simulations using simulated noise delays generated from models of atmosphere, clock, observation noise, and any specific systematic effects
- Compute RMS precision (scatter) and bias of estimated parameters of baseline length, site vertical, Earth orientation or scale estimates from the series of Monte Carlo runs